

JCR VSIL Interoperability Testing

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The Joint Center for Robotics (JCR) Virtual Systems Integration Lab (VSIL) is a combination of Robotics Software Models and Tools used to stimulate Hardware or perform evaluations on developing concepts. The models have been developed at the Tank Automotive Research, Development Engineering Center (TARDEC) or other RDECOM labs and centers. JCR VSIL is focusing on supporting the Robotic Systems Joint Project Office (RS JPO) in testing of their developing Interoperability Profiles for FY10.

The RS JPO Interoperability Profiles will need a facility for testing compliance to the profile attributes. The JCR VSIL is building the testing compliance facility in coordination with the development of the Profiles. The first demonstration is planned for May, 2010. This demonstration will measure the latency of controller(s) to simulated and 'live' robotics platform(s) using the RS JPO Interoperability Profile using JAUS AS-4 message standard. Simulated SUGV will respond to mobility, manipulator and pose control operational messages. A message analyzer will verify the correct message is being passed. A simulated TALON will also be measured through a series of JAUS AS-4 messages. 'Live' hardware will consist of TARDEC Intelligent Ground Systems (IGS) Robotics Autonomous Mobility Platform (RAMP) pan/tilt sensor and operator sensor (Software surrogate may be just prototype discovery / authentication services). The Interoperability Profile will be executed using two different OCUs to manipulate the virtual and 'live' hardware.

This paper will discuss the tradeoffs, architecture and design of the testing system and hardware in support of the May demonstration.

Introduction

The Robotics Systems Joint Project Office (RS JPO) has launched an initiative to identify/define interoperability standards to be organized and maintained within a UGV Interoperability Profile (IOP) such that they can be employed by robotics Program Managers in the acquisition of future ground robotics system programs of record, the upgrade of currently fielded systems, and the evaluation and acquisition of COTS components.

A primary goal of this initiative is to leverage existing and emerging standards, to the extent possible, within the UxV community such as private sector groups, Joint Architecture for Unmanned Systems (JAUS) and the Army Unmanned Aircraft Systems (UAS) Project Office Interoperability Profile with an end goal of:

- Facilitating interoperability among new UGV initiatives and legacy systems;

- Facilitating interoperability between controller and UxV robotic system(s);
- Facilitating collaboration between UGV and UAS systems;
- Providing a path forward to standardize interoperable technology solutions to minimize current force UGV gaps; and
- Promoting payload and on-board subsystem commonality/interchange across fielded UGV systems.

As part of the process for developing the IOP Profile, Requests For Information (RFI) were sent out to industry. Through the RFI process it was shown that industry believes that there needs to be an independent testing and compliance facility for analyzing new technology and platforms. In addition, there is a need for certifying IOP messaging compliance to make sure the new technology and platforms can communicate correctly. Further, there is a need for standardized test procedures that ensures that contractors in the industry can develop to and meet the goals of the IOP Profile. The purpose of the

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Virtual Systems Integration Lab (VSIL) is to provide methods of verification and validation to meet these needs.

A demonstration system was developed to show initial latency testing capabilities, monitoring and validation of JAUS messages sent over the network, and introduction of some of the IOP concepts developed. The system was comprised of two simulated SUGV models, an Operational Control Unit, and a surrogate UGV platform with pan-tilt-zoom (PTZ) camera. The system is depicted in Figure 1.

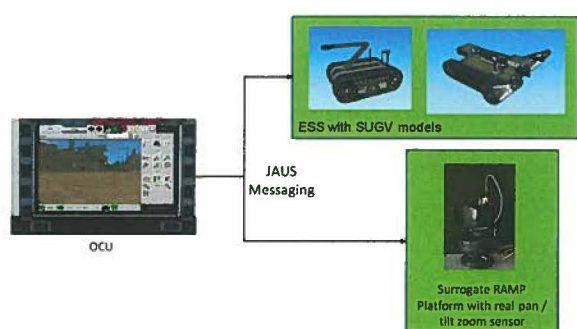


Figure 1: Overall System

Demonstration System

The demonstration system leveraged three products from TARDEC Intelligent Ground Systems: the Embedded Simulation System (ESS) with two simulated SUGV assets, the Scalable Soldier Machine Interface (SSMI) software with layout based on a version used for the Common Controller Interoperability Networking Evaluations, and a surrogate RAMP system utilizing a[1] Pan Tilt Zoom (PTZ) camera. The communication network was comprised of two gigabit switches and a bridge from one switch to the other.

The system uses SAE JAUS messages to communicate from OCU to the simulated assets and from the OCU to the PTZ camera. The PTZ camera also had a simple OCU developed, that also used JAUS. The purpose behind the two OCUs was to show that through the IOP rules, both OCUs could operate a common piece of hardware or software utilizing the JAUS message set and the IOP rules.

JAUS Message Analyzer

SAE JAUS 4.0 messages are used for communications between subsystems of the demonstration system. In addition to the standard the IOP Profile has rules to disambiguate and extend the message set, promoting interoperability. The message analyzer was developed to examine network traffic, identifying JAUS messages and their compliance to the standard and IOP Profile. It can also help to verify correct sequencing of messages.

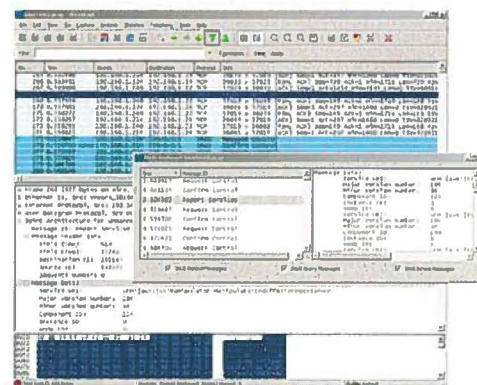


Figure 2: Message Analyzer with Custom Plug-in

The message analyzer is a [3] plug-in (Figure 2). The analyzer has the ability to capture and display network traffic. The plug-in extends its capabilities to include analysis of JAUS messages, and sequences of messages. Figure (3) shows where in the network this tool was used.

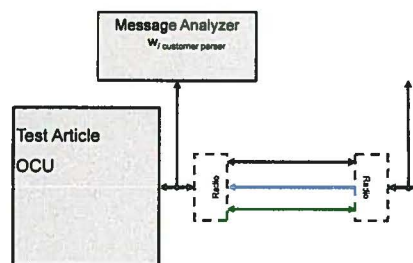


Figure 3: Message Analyzer Use

Each JAUS message is comprised of a JAUS header followed by its corresponding fields. All of which is serialized into a non-human readable format.

The analyzer filters the network traffic looking for the embedded header in order to identify the message as a JAUS message. It then parses each of the fields creating a human readable format which is then displayed in the plug-in. The plug-in maintains

the order in which the messages were sent. This leads to validation of the message format, as well as, the sequence in which they are sent. The capture of message sequences enables verification of required exchanges to accomplish functions such as the discovery, and login. Future work will include the ability to monitor sequences via a specified, user-input, sequence diagram. In other words, the user will create a sequence diagram that details what messages and/or data is to be exchanged, and the analyzer will look for, and validate, that exchange.

Latency

Latency requirements govern the overall system performance and can be defined at various levels. For example, the control of a UGV manipulator can be measured from input on the OCU to the commanded movement of the manipulator or at various points along the thread to include OCU to communications link transmission, communications link transmission to communications link reception, communications link reception to manipulator. The IOP Profile will define what latencies are of importance and as the profile is extended new types of tests will be identified and implemented.

Vendors following the IOP Profile should be able to calculate latencies along critical paths for their systems. However, in order to prove that the vendor's platform meets the IOP Profile, the vendor might need to make known proprietary information used in calculating these latencies. The tests that will be discussed in the following sections should lead to a method that, not only, protects a vendor's intellectual property, as well as, make measurements across differing platforms directly comparable.

Measurements of latency can be grouped into two kinds: intrusive, and non-intrusive. Intrusive measurements are typically done with timestamps embedded into the programming code at various places of interest within a thread. For example, a timestamp might be generated when a joystick is pushed forward which issues a command to a robotic platform ordering it to move forward. On the platform side, another timestamp is used to capture when the robotic platform has received the command. This latency gives the latency between the generation and consumption of the command. There are a few

problems with this type of latency measurement. The first is that the generation and recording of the timestamp takes up CPU cycles and thus adds to the latency. The second is that the timestamps on different CPUs have to be based on synchronized clocks. The third issue is that part of the overall latency cannot be measured. For instance, using this type of measurement technique, the joystick's reaction latency (e.g. *mechanical rotation* → *electrical signal*) and the robotic platform's reaction latency (e.g. *command* → *motion*) cannot be measured. Equation (1) shows an example latency thread.

$$L_{system} = l_{physical-controller} + l_{OCU} + l_{network} + l_{robot-cpu} + l_{robot-actuator} \quad (1)$$

In order to combat these problems of intrusive methods, non-intrusive methods have been devised. An example is the TARDEC Robotic Vehicle Control Architecture (RVCA) ATO where GPS and high speed camera were used to obtain tele-operation control and video latency measurements. Such a method enables testing in the field with high degree of accuracy. However, such a method can also be costly to implement. For this reason, the JCR-VSIL team decided to investigate and validate cost effective methods.

For this demonstration, three methods of non-intrusive methods of latency measurement were introduced. These methods use Micro Electro-Mechanical Sensors (MEMS) in order to measure mechanical actions or electrical signals at the endpoints (i.e. generation and consumption of commands/signals) of a latency pathway. There are a variety of MEMS type sensors on the market that can be utilized for measuring latencies. For instance, through the use of a tilt-sensor (specific application of an accelerometer) or a rate gyro (measures rotation), the test application can measure the mechanical movement of a joystick, indicating when the operator has generated a command to the robotic platform.

The MEMS are placed at endpoints of a latency path to be measured. For instance, the latency from the generation of a command to the consumption of the command and consequent actuation, would have

a MEMS mounted on a joystick and another MEMS mounted on the actuator the command is sent to. The joystick and the actuator are the endpoints of the latency path. The signals from each of the MEMS are read via an oscilloscope. Time is derived from the oscilloscope's measurements, and is centric to the system, i.e. no synchronization across platforms is necessary. Typically, the measurement is taken between the rising edges of two analog pulses recorded from the two sensors, positioned at the endpoints of the latency to measure.

These types of measurements do have some uncertainty associated with them, such as the response time of the sensors, but through careful design and methodical sensor selection, this can be minimized and characterized. Also, measurements need to take into account human-error. For instance, a rate gyro attached to a joystick will often have "bounces" in the beginning of the rising edge of the pulse due to a human pressing forward at an inconsistent speed on the joystick. If the falling edge of the curve was used to determine the latency in turning off the actuator, the joystick returning to its central position, and "bouncing" would have to be taken into account. In order to minimize the uncertainty introduced by human or equipment variability, an electro-mechanical harness may be devised. Without a mechanism with repeatable force in actuating control devices, it will be difficult to characterize the precision of the measurement method (unless the human variability is considered part of the method). The resources and time allocated for this initial capability demonstration did not allow for such development, but this is an aspect that should be investigated in future follow-on effort.

Non-Intrusive Latency Measure Concepts

There were three latency measurement tests developed for the demonstration system. The first was a round trip latency from *command and control(C2) → teleop video feedback on the OCU*. The second was the latency from *C2 → actuator movement*. The third method was a worst case latency from *video recording → display on an OCU*. Each of these is described in more detail in the following sub-sections, as well as, two sections dedicated to the types of sensors used. Following the

sections on each type of latency measurement is a corresponding equation that details the path and endpoints of what is being measured.

Rate gyros measure rotation about an axis. A rate gyro can have multiple axis of rotational measurement; however, a single axis of rotation was all that was needed for this demonstration system. The gyros themselves have maximum frequency response of 100 Hz, translating into roughly 10ms of potential error that needs to be introduced into the overall latency calculation. For some latency requirements, this may be sufficient accuracy, but many systems may require sub millisecond accuracy.

In addition to the rate gyros, accelerometers were considered, specifically a tilt sensor application of an accelerometer. Accelerometers often times have quicker response times. This also implies that they are subject to more noise introduced by the environment. For this experiment, an accelerometer was not tried, but in the future the results from the two types of sensors should be compared in order to determine the best testing equipment.

The photo detector measures light with wavelengths from 350nm to 1100nm and supplies an output voltage proportional to the wavelengths being measured. The output voltage is based on the gain, and the loading of the circuit. The gain is adjustable via an 8 position switch with gains from 0dB to 70dB. Response times of the photo-detector are dependent on the gain setting, and the intensity of the light being measured, and therefore need to be determined before the latency measurement is taken.

A method of determining the response time of the photo-detector is to use a function generator. By connecting the function generator to the oscilloscope and having a square wave pulse a LED, the photo-detector's rise time can be measured. This response time does not correspond directly to the response time introduced by measuring light from an LCD panel. This is an ideal method of measuring the response time of the photo-detector. A method of characterizing the response time from resultant from a change in light color or intensity induced by an LCD panel, which is a slower response, needs to be addressed in the future.

C2 → Teleop Video Feedback on the OCU

One measurement that is of significant importance to the UxV domain, is the time it takes from the generation of a commanded movement to when the operator sees the resultant imagery on the OCU. It is widely understood that successful teleoperation is dependent on the latency between when the operator commands a movement, and when the operator perceives the feedback on the video screen. In order to measure this latency, a rate-gyro was attached to the joystick to measure the time at which the command is initiated, and a photo-detector was placed in front of the OCU screen to detect a change from black to white. This was done with the simulated assets, using a special terrain database. The simulated database contained a special mode where the robotic platform with its camera sensor would be positioned inside of a virtual 3-dimensional box. This virtual box contained white walls, with one black wall. Initially, the simulated asset's camera-under-test faces the black wall. When the command to turn is initiated via the joystick the asset turns within the box, to face a white wall. The resultant imagery displayed on the OCU's screen switches from black to white, which is captured via the photo-detector.

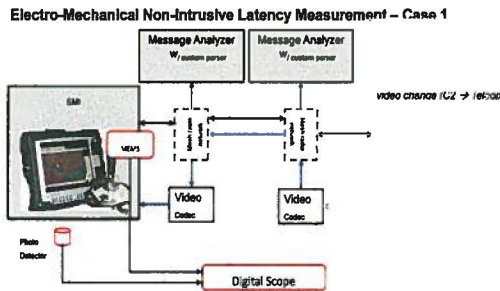


Figure 4: Round Trip Latency C2--> Video Feedback

The gyro captures the initiation of the command, and the photo-detector captures the switch from black to white, and the difference between these two measured times is the round trip latency.

$$L_{system} = l_{joystick-deadzone} + l_{OCU} + l_{network} + l_{robot-cpu} + l_{robot-actuator} + l_{video-update} \pm (l_{gyro-response-time} + l_{photo-detector-response-time})$$

C2 → Actuator Movement

Electro-Mechanical Non-Intrusive Latency Measurement – Case 2

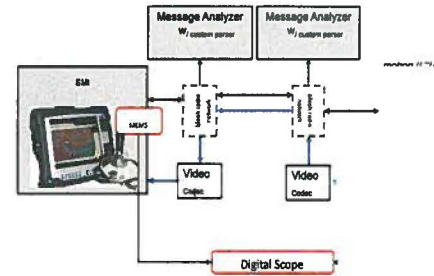


Figure 5: Latency Measure C2 --> Actuator on PTZ

Through the use of two rate-gyros (measure rotation in V^o/S), the latency from the generation of a commanded movement to when the actuator responds and the movement occurs, can be measured. The resulting latency would include the joystick and platform motion reactions, without the use of software captured timestamps. One rate gyro is placed on the joystick, and another is placed on the actuator to be measured. Rate gyros were chosen since both the joystick and the camera's pan actuator rotate about a fixed position. Both sensors are connected to an oscilloscope and the latency measurement can be measured between the trigger signal, e.g. the gyro attached to the joystick, and the resultant output gyro attached to the actuator.

Two things need to be taken into account when measuring this latency. The first is that a joystick has a dead-zone where initial movement from the center position doesn't generate a signal. Measurement of the particular joystick being used should lead to a latency introduced from this which is added to the overall latency equation. The second is the response times of the sensors. In this case there are two rate gyros so the overall equation has a $\pm 2(l_{gyro})$ term, which leads to the following equation:

$$L_{system} = l_{joystick-deadzone} + l_{OCU} + l_{network} + l_{robot-cpu} + l_{robot-actuator} \pm 2(l_{gyro-response-time})$$

The latency introduced by the joystick's dead-zone is part of the system-under-test. The sensor response times are an artifact of the measurement system, and need to be taken into account as a tolerance on the measurement, but are not part of the latency being

measured. These response times indicate an error plus or minus for the overall measurement.

Video Recording → Display on an OCU

The final latency test measured the latency between when a camera records an image to when it is displayed on the OCU. For this, the camera is placed in a dark environment (i.e. light-tight box) with a light source, and an image/pattern to record. The light source is controlled via a switch which is also connected to the oscilloscope. When the light source is active the oscilloscope will register the same voltage as the light source is using, this is used as the first pulse for the latency measurement. When the light source turns on the camera is already streaming the video feed, in this case a dark room/all black image, to the OCU screen, across the network. Once the light source is turned on the camera has to record a test pattern, compress it, and transmit. A photo-detector in front of the OCU screen captures when the image has changed from dark to a lighted test pattern.

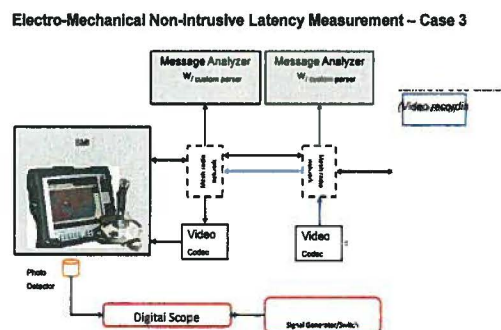


Figure 6: Video Latency

This gives a worst case latency for the time it takes to compress a new image, transmit it, and display it on the OCU screen.

$$L_{system} = l_{joystick-deadzone} + l_{OCU} + l_{network-multiple-hops} + l_{robot-cpu} + l_{camera-capture-and-compression} + l_{video-display} \pm (l_{gyro-response-time} + l_{photo-detector-response-time})$$

Data Collection and Processing

Figure 7 shows a typical sample from the latency test involving two rate gyros. The top data view shows the signals in their raw captured form, and shows a 60 Hz noise introduced from the environment. The bottom data view shows the signals after being run through a 60Hz filter.

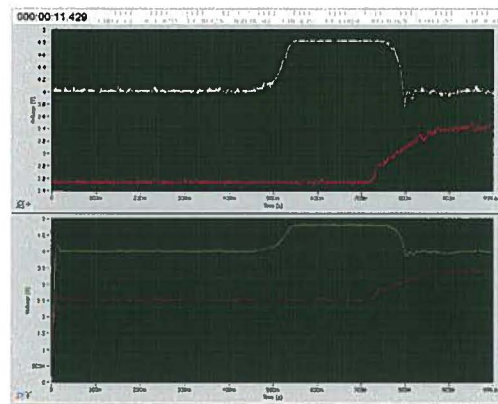


Figure 7: Rate Gyro Test Capture

The signal color-coded white, is the voltage output from the rate gyro attached to a joystick. The pulse indicates that the joystick has moved forward (e.g. rising edge) and then moves backward (e.g. falling edge/joystick returning to center position). The ringing at the end of the falling edge is the joystick bouncing around the center position. The red signal is the output from the rate gyro attached to the top of the PTZ camera, depicted in Figure . Since the camera turns and stops, there is no falling edge on this signal. After filtering the signals in a software program that comes with the oscilloscope used for capturing and processing signals obtained by the oscilloscope, the signals are exported to ASCII files for processing.

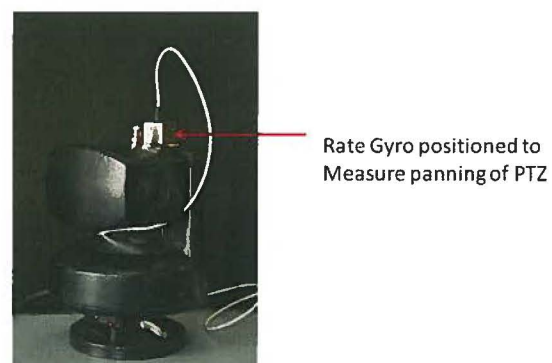


Figure 8

A simple program was developed to measure the steady state response average voltage for 50 ms before the rising edge of the curves, and for another 50 ms after the rising edge. Figure 9 shows a latency measure from roughly 75% of the rise time of the two pulses. The latency is derived from subtracting the time at which each of these points is sampled.

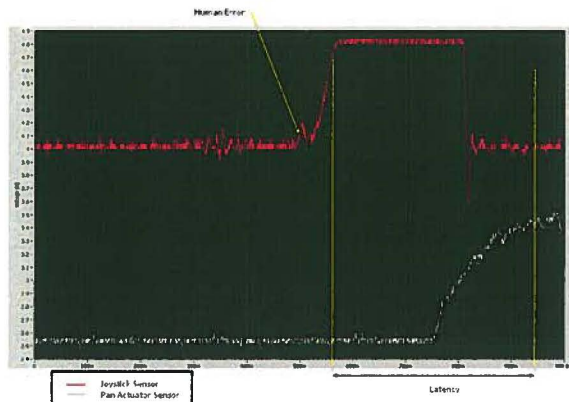


Figure 9: Latency Measure

Choosing Measurement Points

Both precision and accuracy of the measurement methods have to be characterized in order for these methods to be utilized against real systems. Since a system with independently verified latency was not available, the accuracy of the demonstrated method could not be tested. This does not mean that the measurement method cannot be developed. It simply means that the accuracy of the demonstrated measurement technique cannot be defined with confidence.

In order to process the data from a measurement test, two points have to be chosen, one from each of the signals captured. These points also need to be chosen avoid noisy areas. Thus, the simple logic of measuring from close to the start of output signal rising edge does not always work since there could be noise in near the start of the rising edge as can be seen in Figure 9. Although this could be manually judged and an appropriate point determined by “eye balling”, ideally a more automated method would be devised to determine the measurement points so that the measurements can be consistent between test iterations. Choosing these points is problematic when the two sensor’s responses differ.

For instance, referring to Figure 9, it can be seen that the two rate gyros are measuring two different rates of rotation. Thus the differing slopes on the rising edge of the signals. Figure 10 is a simplification of the signals utilizing straight lines.

It can be seen from this figure that the output of the rate gyro on the controller (joystick), has a faster slope than the output of the rate gyro on the platform actuator. This is due to how fast the rate gyros record the events. In this case the human running the test has moved the joystick faster than the actuator on the camera will move the camera.

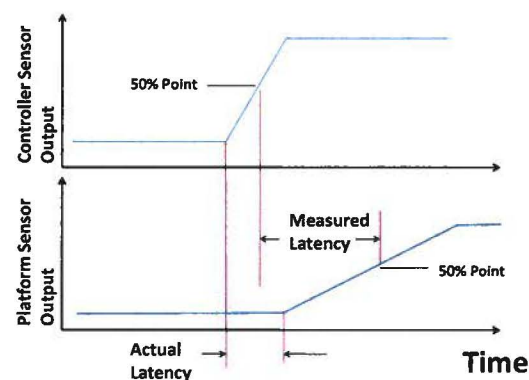


Figure 10: Differing Rise Time Rates: Slower Actuation

Notice that since the second signal has a slower rate, if the latency was determined using the 50% rise time points, the measured time would be greater than the actual time the actuator is responding to that command. In other words, the recorded times have spread out. This indicates that if the latency was measured purely by using the 50% rise time of both signals, and the rate of the actuator was slower than the rate of the joystick, the resultant latency would be greater than the actual latency.

Should the slope of the input signal be slower than the output signal, the opposite happens, as shown in Figure 11. Here the accuracy of the latency measurement has converged on the actual value, but still isn’t accurate. In this case, a latency measured would be smaller than the actual latency of the system. Ideally, the slope of the rise times would be the same for both signals in order to prevent either of these circumstances, but using different types of sensors, or even the same type of sensors measuring a

rate of change that differs from each other, lead to these situations.

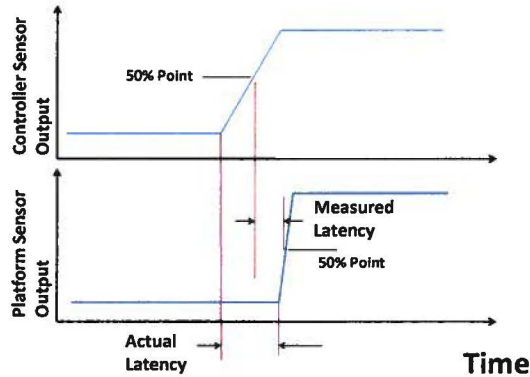


Figure 11: Differing Rise Time Rates: Faster Actuation

Example Results From PTZ

One of the experiments accomplished was to use the second latency test (*command* → *actuation*) on the PTZ with its proprietary controller. The proprietary controller consisted of a display, with a joystick for movement and zoom, with a serial interface to the PTZ camera. This served two purposes. The first was to show that multiple types of OCU joysticks could be tested, and the second, was to show differences between a proprietary controller with a serial interface, versus the SSMI OCU and JAUS messaging. Over a run of ten tests the proprietary controller had an average of 324 ms latency between command and action with a standard deviation of 2.25 ms. The same test was run with the SSMI OCU and included JAUS messaging over a network and the results were 295 ms latency on average, with a standard deviation of 1.92 ms. There was a problem with the data capture of the second test set where the captured signals did not have data samples to get a good average of the steady state of the actuator mounted gyro after the rise of the signal. This is due to the set up of the oscilloscope, and can be corrected easily in the future.

Future Vision

The VSIL effort has shown the capability to provide validation for the initial IOP effort using JAUS messages. The goal is to evolve the IOP over time using a Working Integrated Product Team (WIPT) structure. It is envisioned that the VSIL will continue to evaluate the message set as it evolves.

The architecture approach used during this initial phase was fairly straight forward and the proposed messages achieved the desired effects. In, future IOP versions this may not be the case, approaches may not end with desired results or different approaches may need to be evaluated for latency and other operational parameters. The VSIL in this instance may be needed to perform a testing method for these different approaches.

As the Army's use of robotics evolves, especially into more autonomous missions and roles the needs for more and varied architecture approaches to the IOP are going to be required. These approaches and the resulting operational results will be difficult to quantify for testers. This will require many more iterations of the same test as autonomy does not always provide the same answer. These iterations will provide for a 'bounding' of the solution set. This 'bounding' set will need to be determined by testers to be sufficient or not. Since, traditional range testing is costly and relatively slow, much of this testing will need to be done in a lab setting, using M&S as stimulation and in some cases emulation for robotics systems and subsystems. These M&S developed 'bounding' sets for test solutions will still be validated with 'live' traditional range testing to confirm that they perform within the 'bounding' sets.